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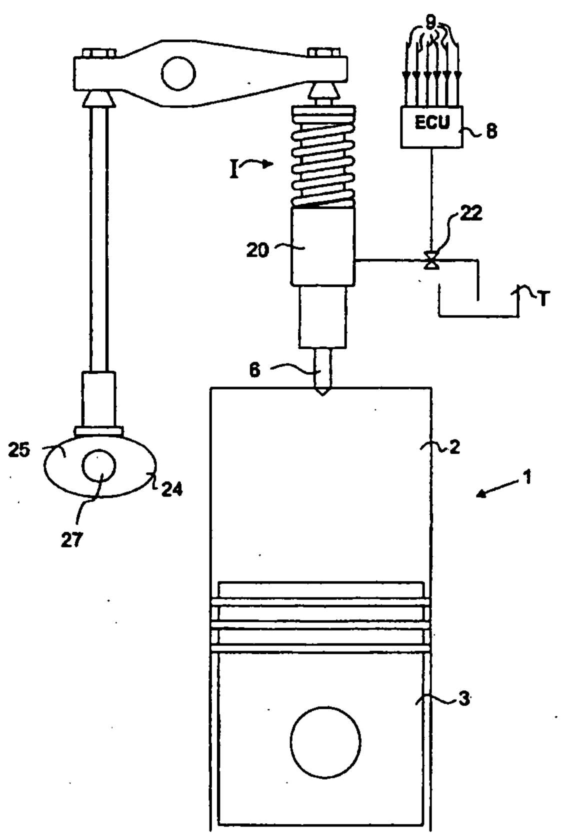
(54) Title: DEVICE AND METHOD FOR FUEL INJECTION



(57) Abstract: A device and a method for injecting fuel into a cylinder (2) of a combustion engine (1), including a camshaft influenced injector unit (I), a controllable control valve (22) connected thereto allowing injection in closed or restricted position, wherein a camshaft (27) for influencing the injector unit is synchronised so as to influence the injector unit for injection during the compression phase of the engine. The camshaft (27) is also synchronised to influence the injector unit (I) for injection during the gas exchange phase and a control unit (8) is arranged to influence the control valve (22) for injection synchronously with the first (24) and/or a second (25) cam lobe on the camshaft, as a response to signals indicating the prevailing operational condition of the engine.

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DEVICE AND METHOD FOR FUEL INJECTION

Field of the invention

The present invention concerns a fuel injection device for a combustion engine of the piston cylinder type according to the preamble of claim 1 and a method for injection according to the preamble of claim 6. Further the invention concerns a diesel engine including such a device.

Prior art

The problems with high NO_x-emissions from conventional diesel engines is a result of very high combustion temperatures at limited locations inside the cylinder during the combustion, since the combustion occurs locally and close to the adiabatic flame temperature, i.e. $\lambda \sim 1$.

In diesel engines different measures have been taken in order to remove these emission problems. As an example there exist combustion engines known as HCCI (Homogeneous Charge Compression Ignition) or ATAC (Active Thermo Atmosphere Combustion) which simply expressed could be defined as a combination of a diesel engine and an Otto engine. Hereby a premixed fuel-air mix is injected into the cylinder said mix being compression ignited when the working piston is positioned near its upper dead centre position in the ignition phase. HCCI engines provide substantial advantages; low or no NO_x-emissions as well as high efficiency, which is in close to that of the diesel engine. In the HCCI engine the above problems are overcome, since lower combustion temperatures will result in an essentially leaner mixture (with high λ), since combustion is initiated essentially simultaneously in

distributed areas of the combustion chamber. All together this results in a more even temperature distribution.

In combustion engines of the kind applying combustion of a homogeneous, premixed fuel-air mixture the emission problem with respect to harmful compounds is obviously possible to reduce. However, this engine type suffers from a number of draw-backs such as narrow load range. In order to obtain acceptable operation it is necessary that ignition occurs at a limited range near the upper dead centre position of the working piston. The start of the combustion, however, depends on several parameters, but firstly on the temperature and the pressure in the combustion chamber. Since in turn the temperature is highly dependent on charge pressure and load, the ignition point of the gas will therefore fluctuate considerably. This results in low motor efficiency and that the thermal load on the engine will become great if the ignition point is too early, which tends to be the case at heavy load. If, on the other hand, the ignition point is late, also in that case the efficiency will be low and further, the combustion will be incomplete resulting in high emissions of HC (hydrocarbons).

A further problem is that the ignition point is not stable. As an example the ignition point is assumed to be in the region of the upper dead centre position of the working piston. A small change of the ignition point in relation to previous ignition conditions with respect to the upper dead centre position gives the engine a corresponding increase of the thermal load. This results in a higher temperature of the next cycle etc, further pushing the ignition point, in direction of earlier ignition with respect to the upper dead centre position, in an escalating process with harmful consequences.

It has been suggested to combine in one engine the HCCI process with the diesel process by injecting a portion of the fuel into the cylinder in the region of the upper dead centre position of the piston in the gas exchange phase. This results in forming a homogeneous premixed fuel air mixture with a first amount of the fuel brought in already during the intake phase. The remaining portion of the fuel to be part of the combustion is directly injected into the cylinder for conventional initiating of the combustion of this portion, whereby the first homogeneously mixed amount is used as a pre-heater and ignition initiator for the subsequently injected fuel amount. This system, however, demands applying extra equipment in the form of special injectors and drives therefore and altogether a non-negligible costs increase for the engine.

Aim and most important features of the invention

It is an aim of the present invention to provide a device and a method wherein the drawbacks of the prior art are eliminated or at least reduced. It is also an aim to provide a device and a method through which enhanced operation of four-stroke combustion engines may be obtained.

These aims are obtained according to the invention by a device and a method for fuel injection of the kind mentioned above being according to the characterising portions of claim 1 and 6 respectively.

Hereby it is achieved that conventional components, typically being present in the combustion engine, may be used after only a slight modification. The respective fuel portions are controllable in an advantageous way so that for each operation condition, adequate apportionment may be obtained.

The inventive principle may be adapted in all diesel engines and with different diesel fuels. In particular the invention may be applied in operation with fuels that are difficult to ignite such as for example ethanol and methanol.

In conventional diesel engines with ethanol as power fuel, in certain types of operation the engine may be operated on pure ethanol, for example at high load. At lower load, however, there are problems with pure ethanol as fuel, resulting in that the fuel conventionally must be admixed with a so called ignition improver, for example a nitrated compound or for example polyethylene glycol. According to the invention, however, diesel operation with fuels that are difficult to ignite, such as ethanol, may be possible without addition of ignition improvers. This is because the first homogeneously mixed fuel portion at for example low load, in practice will function as an ignition improver and, according to the above in practice also as a pre-heater, so that the second injected portion is securely ignited at the desired point.

The injection of the first portion of the fuel is made in a phase where heat residual gases from a previous combustion cycle remains inside the cylinder, promoting evaporation of the injected fuel. This is particularly effective in case of diesel oil. Ethanol could be injected later, since it is more volatile. During the suction phase sucked in (or charged) air is allowed to be effectively mixed with the evaporated or at least essentially evaporated fuel, so that a homogeneous fuel-air mixture will result in the entire combustion chamber.

By varying the proportion between the first and the second portion depending on providing operational condition, the engine operation may be optimised. The efficiency in a broad spectrum of cases of operational will thereby increase. As an

example it could be mentioned that in normal running on full load, it may be possible to manage with a small first portion fuel supplied for establishing a homogeneous fuel mixture, whereas at lower load it is desirable to have established a greater amount of homogeneous fuel-air mixture.

According to the invention, low NO_x-emissions will result and it may be advantageous also for that reason to arrange such that the supplied fuel at idle running and low load solely or at a large extent is comprised of "the first portion" fuel. The invention also has a considerable potential to reduce soot formation. A certain reduction of fuel consumption can also be expected.

Through the construction with double cam lobes on the camshaft effecting the injector unit, the engine in principle only has to be supplemented with one cam lobe, which influences the injector at a chosen time distance from the ordinary cam lobe, and software. The amounts of fuel to be injected at the different occasions are controlled by a control valve, which roughly functions as a bleeding valve, such that injection will take place when it is closed but not when it is open. For that reason, according to the invention, the control system has to be programmed for a correspondingly altered control valve control.

By, according to one aspect of the invention, the first cam lobe being provided with a cam surface, for influencing an injector unit, having another pitch than the corresponding cam surface of the second cam lobe, it is achieved that the injection pressure may be controlled during the injections. This may i.a. be used for influencing the duration of the injections.

By, according to a further aspect, the first cam lobe being synchronised to influence the injector unit before any essential suction intake has taken place in the gas exchange phase, remaining heat energy in residual gases, piston top etc will be utilized at a higher degree.

Further advantages are achieved with different aspects of the invention and will become apparent from the following detailed description.

Brief description of the drawings

The invention will now be described in more detail by way of embodiments and at the background of the annexed drawings, wherein:

Fig. 1 diagrammatically shows a detail of a combustion engine equipped according to the invention,

Fig. 2 shows a first variant with a differently constructed cam lobe,

Fig. 3 shows a second variant with a further differently constructed cam lobe,

Fig. 4 diagrammatically shows the use of the control possibilities of the invention in a torque/rotation speed curve for a diesel engine, and

Fig. 5 shows a PV diagram for a diesel engine.

Description of embodiments

Fig. 1 shows diagrammatically a multi-cylinder (one single cylinder shown) diesel type combustion engine 1 comprising a cylinder chamber 2 and a piston 3 movable in said cylinder. An intake channel debouches into the cylinder chamber 2 from

where also an outlet channel starts, which as usual are equipped with appropriate valves (this is not shown). As usual (at least) one injection nozzle 6 is arranged for direct injection of fuel into the combustion chamber. The nozzle 6 is connected to a cam-driven injector I of a conventional type including a cam operated piston (not shown) inside a cylinder 20. A camshaft 27 carries on the one hand a conventional second cam lobe 25, which influences the injector I at the ignition phase, on the other hand a first cam lobe 24, which is displaced about 180° with respect to the second cam lobe in order to allow injection effect during the gas exchange phase of the engine. A control valve 22 is in a per se known manner arranged at a discharge from the injector, so that injection will result when the valve is closed and the injector is influenced by a cam lobe. Open control valve results in bleeding off of the fuel amount being present in the cylinder to the tank T. The fuel amount may thus be controlled by controlling closing time for the valve 22 and possibly also to what extent it is open. This is dealt with by the control unit 8.

The control system in Fig. 1 includes a control unit 8, which is supplied with signals 9 concerning running parameters with respect to engine operation, which could concern rotational speed, load, engine temperature, accelerator pedal position, exhaust gas composition etc. The control unit 8 is arranged to control the control valve 22 in order thereby to control fuel amount injected through the injection nozzle 6 every time of influence.

Preferably the control unit is programmed to optimise the apportionment between the injected fuel amounts and also the total amount injected fuel and possibly also, to a certain

extent, the time when the respective injection will occur with respect to the crank shaft angle of the engine.

The invention may be modified within the scope of the claims, and in particular the relation between the different portions may be adjusted for different operational conditions, as is indicated above.

It is also possible to arrange locations and numbers of the injection nozzles to the conditions prevailing in a specific engine. The nozzle 6 and the associated fuel circuit may have a conventional construction and place, and the same goes for the control valve 22.

In Fig. 2 alternatively shaped cam lobes are shown where the first cam lobe 24 has a cam surface for influencing the injector unit with a larger extension and thereby greater pitch than the corresponding cam surface of the second cam lobe 25. In Fig. 3 further alternatively designed cam lobes are shown wherein the first cam lobe 24 has a cam surface for influencing the injector unit having a smaller extension and thereby smaller pitch than the corresponding cam surface of the second cam lobe 25. By choosing the shape of the cam surfaces this way and in any similar way it is achieved that the length of the injection time may be controlled for the different injection occasions. Generally injection over a longer time period with lower injection pressure will result from lower inclination.

In Fig. 4 an example is illustrated on the possibility of varying the relation between the first and the second portion depending on the prevailing operational condition, so that the engine operation may be optimised. The efficiency will thereby increase at a broad spectrum of operational cases. As is

apparent from the example, in normal driving with high load (upper area in the figure over about 50-60% of full load) it is possible to run on "diesel mode" (combustion according to the diesel process) and thus manage without or with a small first portion of fuel supplied in order to establish a homogeneous fuel mixture. At low load (the bottom area below about 15% of full load) it is desirable to have a greater amount established homogenous fuel-air mixture for best operation. Here "HCCI mode" thus prevails (combustion according to the HCCI process). In the middle area it is foreseen that one achieves a varying mixture in the direction of a more "diesel mode" with increasing load. It should be noted that the shown example just roughly explains the principle of the invention.

The PV diagram in Fig. 5 shows a diesel cycle with outlet phase 12, intake phase 13, compression phase 14, ignition phase 15 and expansion phase 16. Principally the first portion is injected at the start 17 of the intake phase 13, whereas the second portion is injected, as conventionally, at the start 18 of the ignition phase 15 or the termination of the compression phase 14.

The moment for injecting the first portion of the fuel is controlled so as to ensure that the fuel is injected as close to the upper dead centre position of the piston that no fuel will risk to reach the cylinder lining. If instead the fuel would have been injected during a part of the intake phase where the lining is exposed, this would in the prevailing environment negatively affect the lubricating film. Further, sucked in cool air would prevent vaporising of the fuel due to the cooling effect.

Injection should by the way be made so that the spray of fuel-drops is directed down into a cavity that is arranged in the piston top, whereby also the heat of the piston is used to promote combustion. The injector may by the way be influenced directly by a overhead camshaft.

The compression is adapted to the fuel and in case of diesel oil it is preferably within a compression region between about 9-14:1, whereas in case of ethanol it is preferably about 19-24:1. Also a so called "PLD"-injector would be used, i.e. an injector with the pump separated from the injector itself and connected thereto by a tube, which gives greater freedom of positioning these elements with respect to the camshaft.

Preferably the control unit is arranged such that in operation 0-100% of the total fuel amount is injected synchronously with when the first cam lobe influences the injector unit for optimal covering main part of the operational cases which could be expected. Also other, essentially more narrow intervals may however come into question: about 3-20% of the total fuel amount, and it is preferred that about 5-15% is injected synchronously with the first cam lobe effecting the injector unit. At about 3-10% pre-injection it is desired that the supplied amount burns in advance and comprises a pre-heater, whereas at a higher portion of pre-injected fuel, above 10-60%, everything is to burn simultaneously, i.e., at the over dead centre position in order i.a. to avoid knocking.

The invention may be combined with controlling valve overlap so that an increased amount of residual gases will remain in the cylinder for enhanced fuel vaporisation. This may result in a possibility of pre-injecting a greater amount of the fuel. Further, preferably EGR recycling is provided in order

to obtain further optimised operation and emission reduction, in particular at loads over 50% of full load.

Claims

1. Device for injecting fuel into a cylinder (2) of a combustion engine (1), including a camshaft influenced injector unit (I), a controllable control valve (22) connected thereto allowing injection in closed or restricted position, wherein a camshaft (27) for influencing the injector unit is synchronised so as to influence the injector unit for injection during the compression phase of the engine, **characterized in** that the camshaft (27) is also synchronised to influence the injector unit (I) for injection during the gas exchange phase of the engine and that a control unit (8) is arranged to influence the control valve (22) for injection synchronously with the first (24) and/or a second (25) cam lobe on the camshaft (27) for injection during the gas exchange phase and during the compression phase respectively, as a response to signals indicating the prevailing operational condition of the engine.

2. Device according to claim 1, **characterized in** that the first cam lobe (24) has a cam surface for influencing the injector unit (I) that has another inclination than the corresponding cam surface of the second cam lobe (25).

3. Device according to claim 1 or 2, **characterized in** that the first cam lobe is synchronised to influence the injector unit at the start of the intake phase.

4. Device according to claims 1, 2 or 3, **characterized in** that the cam lobes are displaced about 180°.

5. Device according to any of the previous claims, **characterized in** that the control unit is arranged such that in operation 3-100% of the total fuel amount is injected

synchronously with the first cam lobe influencing the injector unit.

6. Method for injecting fuel into a cylinder (2) of a combustion engine including a camshaft influenced injector unit (I), a controllable control valve (22) connected thereto, which allows injection in a closed or restricted position, wherein a camshaft (27) for influencing the injector unit synchronously influences the injector unit for injection at the end of the compression phase of the engine, **characterized in** that the camshaft (27) is also synchronised so as to influence the injector unit (I) for injection during the gas exchange phase of the engine and that the control valve (22) is controlled for injection synchronously with a first (24) and/or a second (25) cam lobe for injection during the gas exchange phase and the compression phase respectively as a response to signals indicating the prevailing operational condition of the engine.

7. Method according to claim 6, **characterized in** that the first cam lobe influences the injector unit at the start of the intake phase.

8. Method according to claim 6 or 7, **characterized in** that the injector unit is influenced by cam lobes being displaced about 360 crank shaft degrees corresponding to about 180 camshaft degrees.

9. Method according to any of the claims 6-8, **characterized in** that in operation 0-100% of the total fuel amount is injected synchronously with the first cam lobe influencing the injector unit.

10. Method according to claim 9, **characterized in** that in operation about 3-20% of the total fuel amount and preferably

about 5-15% is injected synchronously with the first cam lobe influencing the injector unit.

11. Method according to any of the claims 6-10, **characterized in** that when low engine load and moderate rotational speed has been established, the injected portion at the end of the compression phase is minimised.

12. Method according to any of the claims 6-11, **characterized in** that when high engine load has been established the injected portion at the end of the compression phase is maximised.

13. Method according to any of the claims 6-12, **characterized in** that when low engine load and high rotational speed is established the injected portion at the end of the compression phase is set on an intermediate value.

14. Diesel engine including a device according to any of the claims 1-5 for each one of its cylinders.

15. Diesel engine according to claim 14, wherein it also includes means for controlled EGR gas recycling.

16. Diesel engine according to claim 14 or 15, wherein it also includes means for controlling the opening times for the intake and outlet valves.

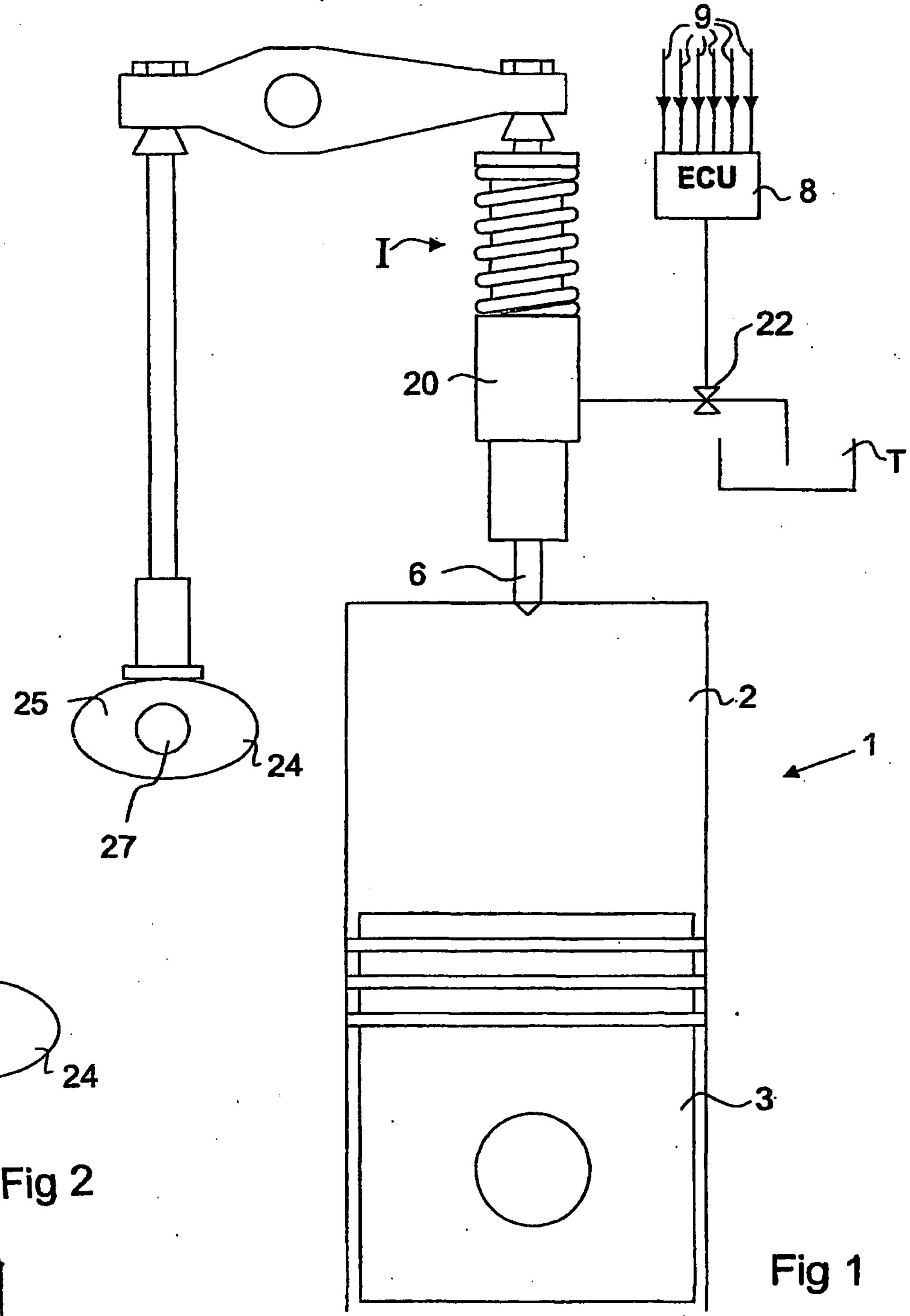

Fig 1

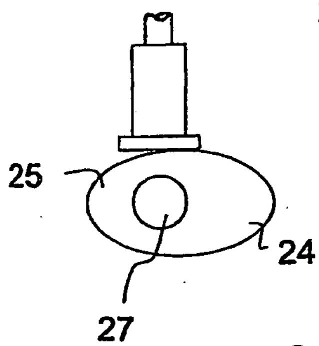

Fig 2

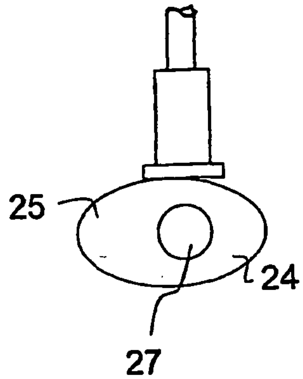

Fig 3

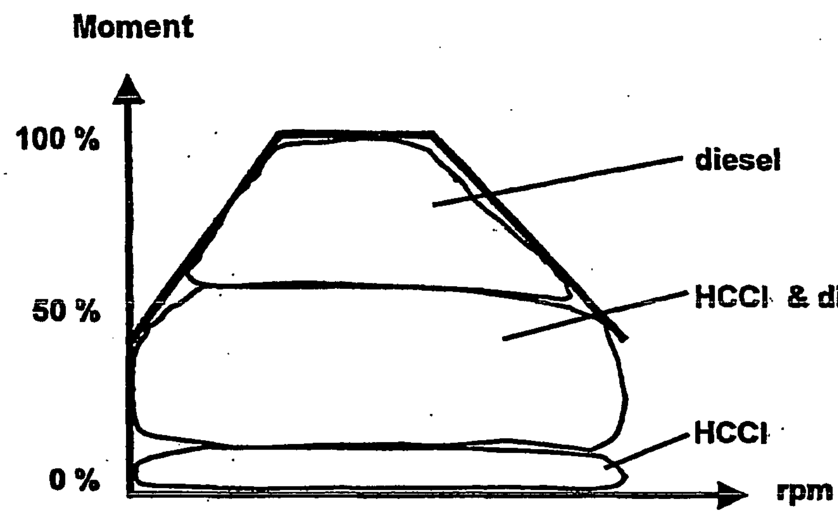
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FIG 4

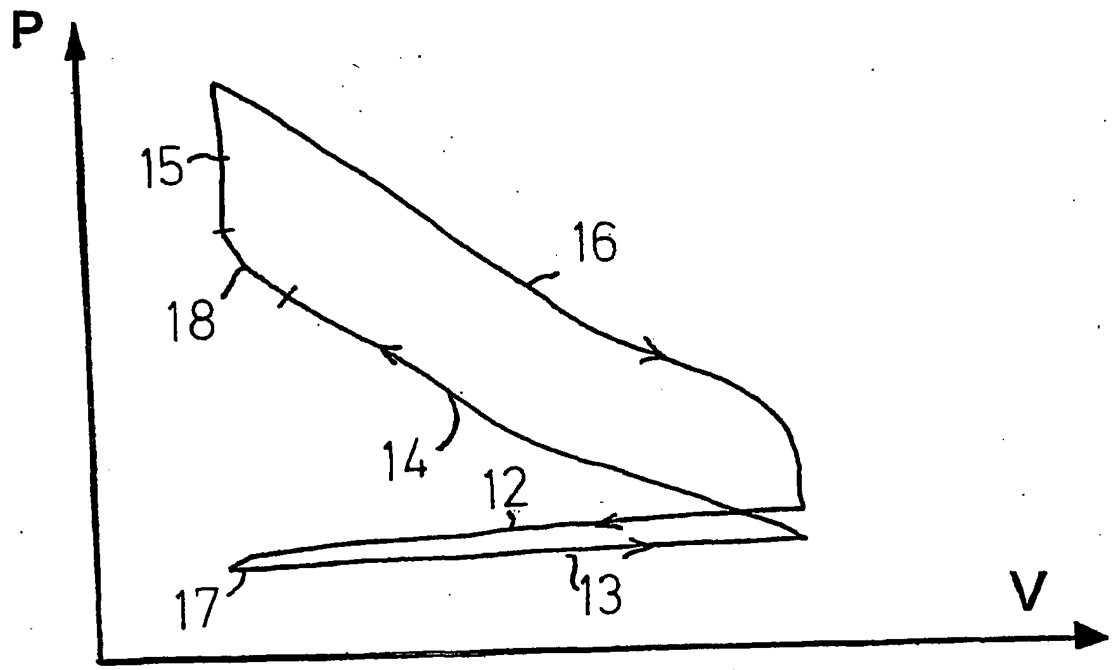
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FIG 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 01/00923

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: F02D 41/40, F02M 45/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: F02D, F02M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5740775 A (SUZUKI ET AL), 21 April 1998 (21.04.98), abstract	
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A	US 5697343 A (ISOZUMI ET AL), 16 December 1997 (16.12.97), abstract	
	--	
A	US 6082325 A (DIGESER ET AL), 4 July 2000 (04.07.00), abstract	
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☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
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"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
31 May 2001	19 -06- 2001
Name and mailing address of the ISA/ Swedish Patent Offic Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Dan Ionesco / JA A Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

Information on patent family members

30/04/01

International application No.
PCT/SE 01/00923

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5740775 A	21/04/98	EP 0767303 A	09/04/97
		EP 0967380 A	29/12/99
		JP 9158810 A	17/06/97
US 5697343 A	16/12/97	DE 19708152 A,C	15/01/98
		FR 2750740 A	09/01/98
		JP 10026059 A	27/01/98
US 6082325 A	04/07/00	DE 19750226 C	29/10/98
		EP 0916829 A	19/05/99